

**Senior Thesis**

**Interpretation of the Fresh Water/Brine Interface of the Devonian/Silurian  
Carbonates of Central Ohio**

by

C. Steven Compton II

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requirements for the degree of Bachelor of Science in  
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Approved by

A handwritten signature in black ink, appearing to read "E. Scott Bair", is written over a horizontal line.

Dr. E. Scott Bair

## **ABSTRACT**

This thesis was conducted to determine the relation between the brine horizon and the beds of the Devonian/Silurian carbonate units known by the drillers' name, Big Lime. The relation can take three forms: A) the brine horizon dips parallel to its parent bed, B) the brine horizon dips at a steeper angle than its parent bed, or C) the brine horizon dips at a shallower angle than its parent bed. It is important to know this relation so that an approximate depth to brine can be determined during the drilling of oil and gas wells, which contain brine as a by-product, in addition to determining the depth at which brine can be found for the injection of waste brine.

Data as to the depth to the "First Brine" of the Big Lime and the top of the Big Lime was determined using oil and gas "header cards" archived in the Geologic Records Section of the Ohio Department of Natural Resources Division of Geological Survey. The data were imported into SURFER for Windows and contour maps were made of the top of the Big Lime and the elevation of the First Brine Horizon. These maps were compared and the relation between the brine horizon and the top of the Big Lime was determined. This relation agrees with Scenario B above.

Utilization of these findings makes it possible to determine the relative placement of the Big Lime's brine horizon compared to its upper surface. This information will aid drillers and environmental scientists in the determination of where brine will be encountered and where brine can be found for the disposal of petroleum-industry brines by injection.

## ACKNOWLEDGEMENTS

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I also wish to thank Kristen Kudless for her unyielding support during the writing of this thesis and through most of my college years. My grandparents for always being there for me. And finally thanks to my parents for their emotional and financial support over my college career.

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## **INTRODUCTION**

Each year demand increases for groundwater of high chemical quality for domestic and industrial use. As industry increases, the need for waste disposal also increases. One method of disposal of liquid waste from the oil and gas industry is by injection into aquifers containing brine. To insure that any waste injected does not migrate to aquifers used for drinking water, it is necessary to understand the extent and nature of not only the aquifers and confining layers, but also the relation between the brine and freshwater in the aquifer.

The injection of oil and gas industry waste into brine aquifers is ideal because the majority of the liquid waste generated by the oil and gas industry is brine. The amount of brine recovered during the production of oil or gas varies widely but in nearly every case there is some brine associated with production. This waste needs to be disposed of and re-injection is a method that is permitted in Ohio and in other states. To inject brines one must know where the brine can be safely reintroduced to the subsurface and where it will migrate in the regional flow regime after injection.

### **Purpose and Scope**

This thesis endeavors to determine the extent of the brine horizon within the Devonian-Silurian carbonate units in central Ohio (Figure 1). Using data from the drilling of oil and gas wells, I hope to show the downdip extent of the freshwater/brine interface in the Devonian-Silurian carbonate units, which are known collectively to drillers as the Big Lime.

The orientation of this interface is thought to occur in one of three configurations: A) the brine horizon runs parallel to the dip of the carbonate beds it is in, B) the brine horizon plunges at a steeper angle than that of the dip of the carbonates, C) the brine horizon descends at an angle shallower than the dip of its surrounding beds. Figure 2 shows the three possible configurations.

**Figure 1.**

**Map of Ohio with Study Area Highlighted and Cross-Section Lines, A-A', B-B', C-C', and D-D'.**

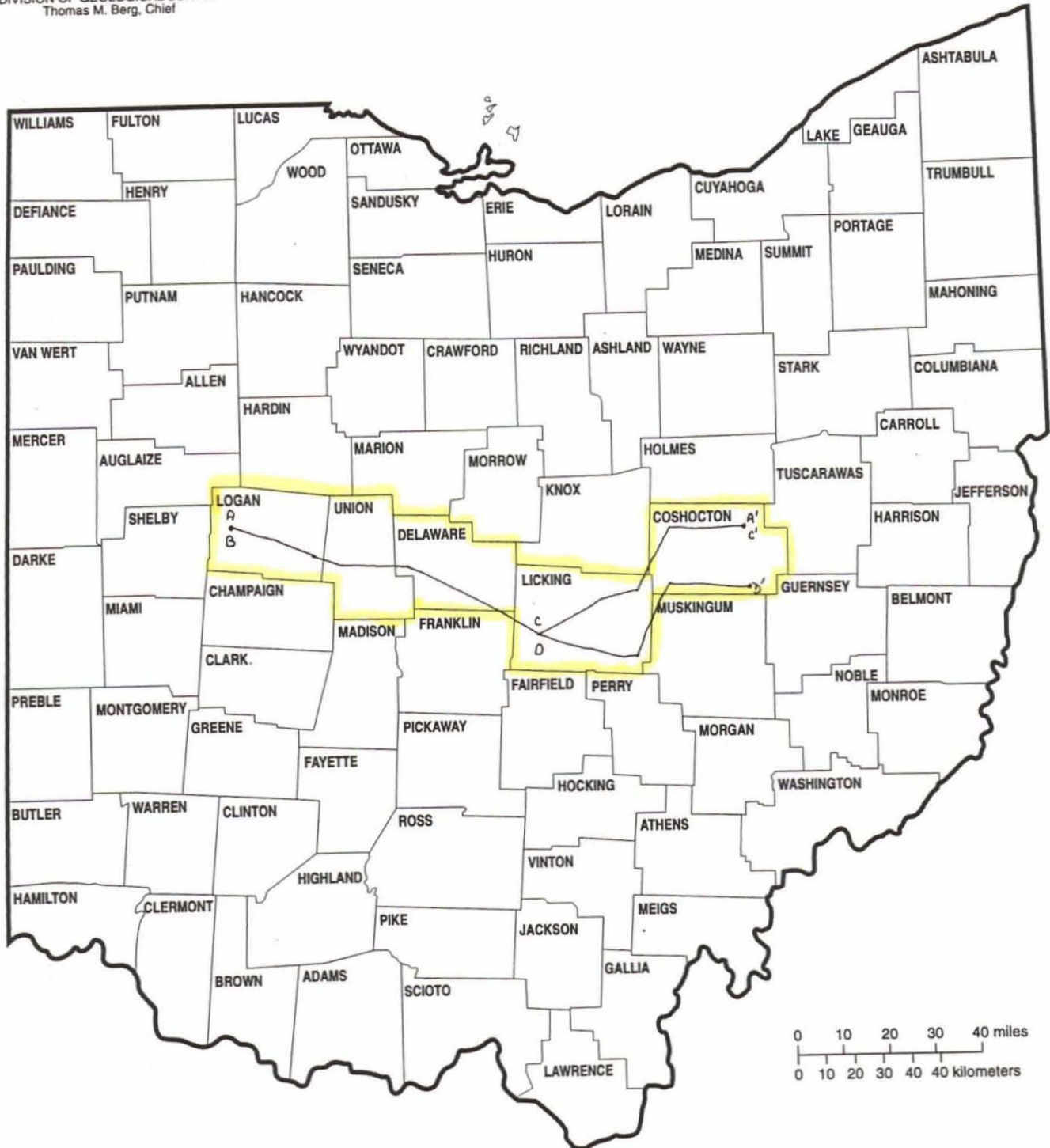
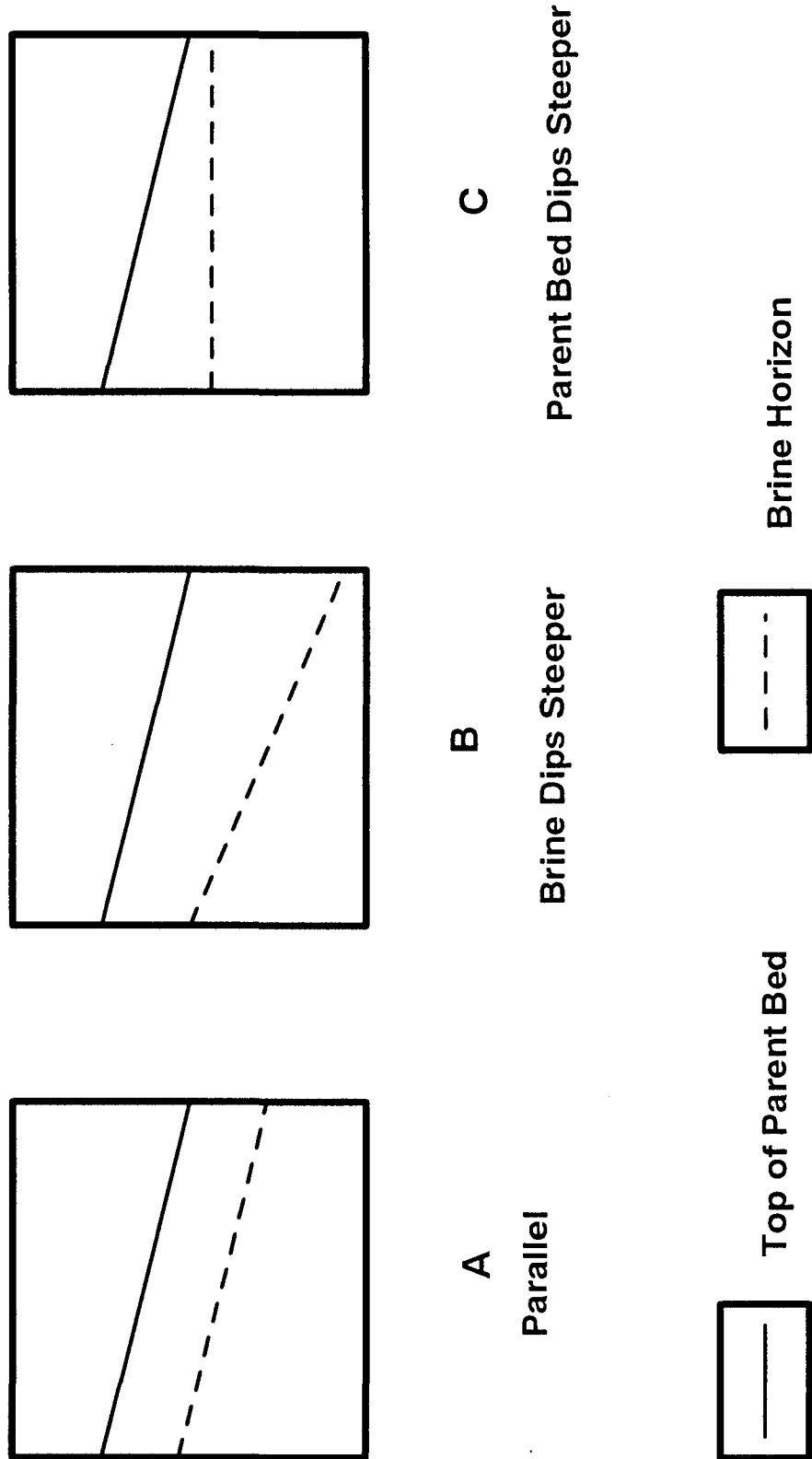




Figure 2. Possible Brine Horizon/Parent Bed Relations



## **Previous Studies**

I found no other studies in the literature that cover the relation of a brine horizon to the beds in which it is found. However, Stout *et al* (1932) published a study describing the brines of Ohio. They described the brines associated with the differing rock units found in Ohio, the historical use of brines, and the modern utilization of brines. Their discussion of the brines found in Ohio's rock units is included in the Geologic Setting portion of this thesis.

The chemical and isotopic characteristics of brines in eastern Ohio, as compiled by Breen *et al* (1985), is another useful publication. Their investigation looked at the brines found in oil and gas producing sandstones in eastern Ohio. The purpose of their study was to determine the origin and movement of brines from different formations by their chemical and isotopic characteristics. This information may allow for the tracing of contamination back to the formation of origin. It also aids in determining if contamination due to poor well construction or from damaged well casing has occurred.

## **Methods of Analysis**

Data utilized for this thesis were compiled from the "header cards" listing the drilling data recorded during oil and gas well completion. These data are archived in the Geologic Records Section of the Ohio Department of Natural Resources (ODNR), Division of Geological Survey. Wells were chosen by their being completed through the Devonian-Silurian carbonates and their having a recorded depth to brine. Figure 3 is an example showing a typical oil and gas well "header card".

Figure 3. ODNR Well "Header" Card

DUPLICATE

County COSHOCTON Township PERRY Permit no. 4739  
 Section 23 Lot      Tract      Permit issued 12-31-81  
 Measured 1108' SL & 1662' WL of Sec. 23 Twp. quarter       
74.6 Acres

Land owner Richard M. Haines Well no. 2 Date commenced 2-20-83  
 Operator ( J B Excavating ) Biggs Jerrold L. Well no.      Date completed 3-14-83  
 Elevation bar 862' Total depth 3064' Plugged back       
 Formation drld. to Clinton Prod. form. Clinton Prod. nat. s/oil  
F/W 1800 BW & 250 sks. sand; I.P. A.F. 2 B0  
 Init. rock press.       
 Casing record 10" 31', 8" 426', 61 sks. mud, 4½" 3064', 35 sks Abandoned 5-25-85

Formation	Top	Bottom	Remarks	Formation	Top	Bottom	Remarks
COMPLETION 4-16-84							
FW	0	30	FW @ 70'	X=2,097,400 Y= 815,850			
Big Injun sand	100	735		PLUGGING REPORT 1-28-86			
Berea sand	715	725					
Big Lime	1950	2845	SW @ 2615' 3 BPH				
Pkr. sh.	2962	2992					
White Cl.	3015	3064	s/oil				

## **GEOLOGIC SETTING**

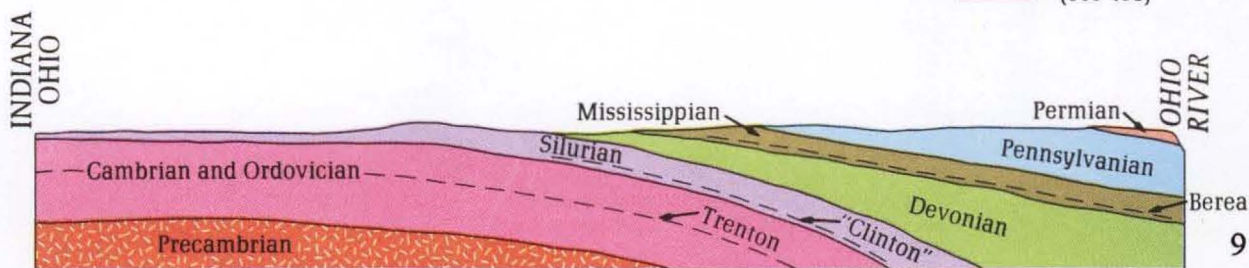
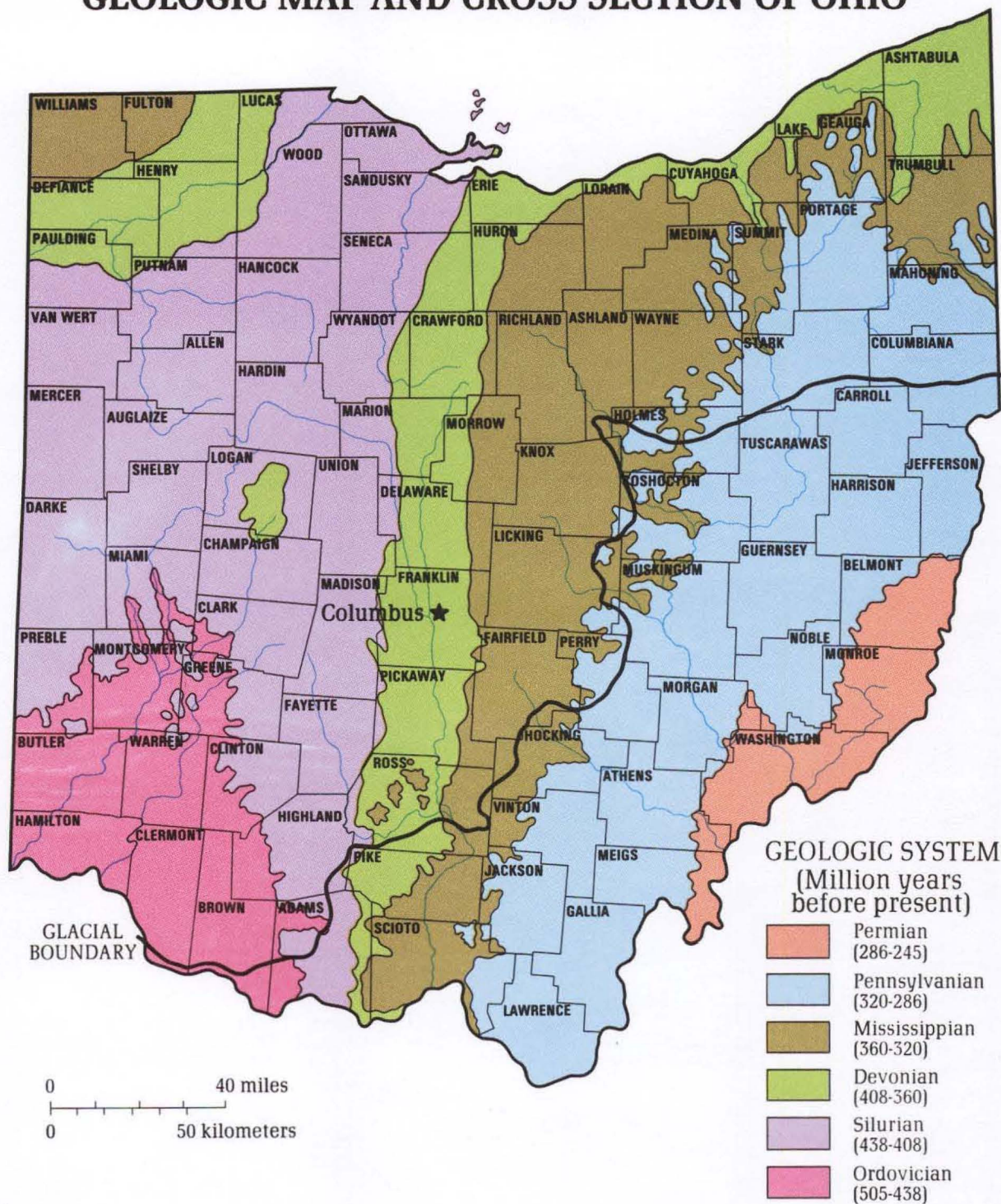
Bedrock outcrops in central Ohio contain a wide range of geologic units deposited between 286 and 430 million years. Each of these geologic units plays an important role in defining the nature of Ohio's bedrock aquifers and confining layers, and in determining the quality of the water contained in them. These units are shown in Figure 4, the Geologic Map of Ohio, and in Figure 5, the Glacial Deposits Map of Ohio, which overlie bedrock throughout much of the state.

In Logan County, to the west, mostly Silurian carbonates are found with an isolated central outcrop of Devonian carbonates, which are covered by ground and end moraine. To the east in Union County, Silurian and Devonian carbonates are overlain by ground and end moraine. Further east in Delaware County, Silurian and Devonian carbonates and Mississippian sandstones and shales are overlain by glacial deposits. Still further east in Licking County, primarily Mississippian sandstones and shales occur with small areas of Pennsylvanian age rocks. The glacial boundary occurs along the eastern border of Licking County. In Coshocton County, a thin band of Mississippian sandstones and shales occurs in the central and northwestern portions of the county with the remainder being Pennsylvanian rocks. Only the western border of Coshocton County is glaciated. All these rocks dip east, off of the eastern flank of the Cincinnati Arch. The Cincinnati Arch is an anticline. Its axis runs northeast-southwest through the western portion of the state.

Figure 1 is a map of Ohio showing county boundaries, the outline of the study area, and cross-section lines A-A' and B-B'. Cross-section A-A' shows the structure and rock units across the northern part of the study area (Figure 6). Cross-section B-B' covers the southern portion of the study area (Figure 7). The study area includes Logan, Union, Delaware, Licking, and Coshocton Counties. Figure 8 is the stratigraphic column of the State of Ohio. It lists the accepted geologic

**Figure 4.**  
**Geologic Map of Ohio**

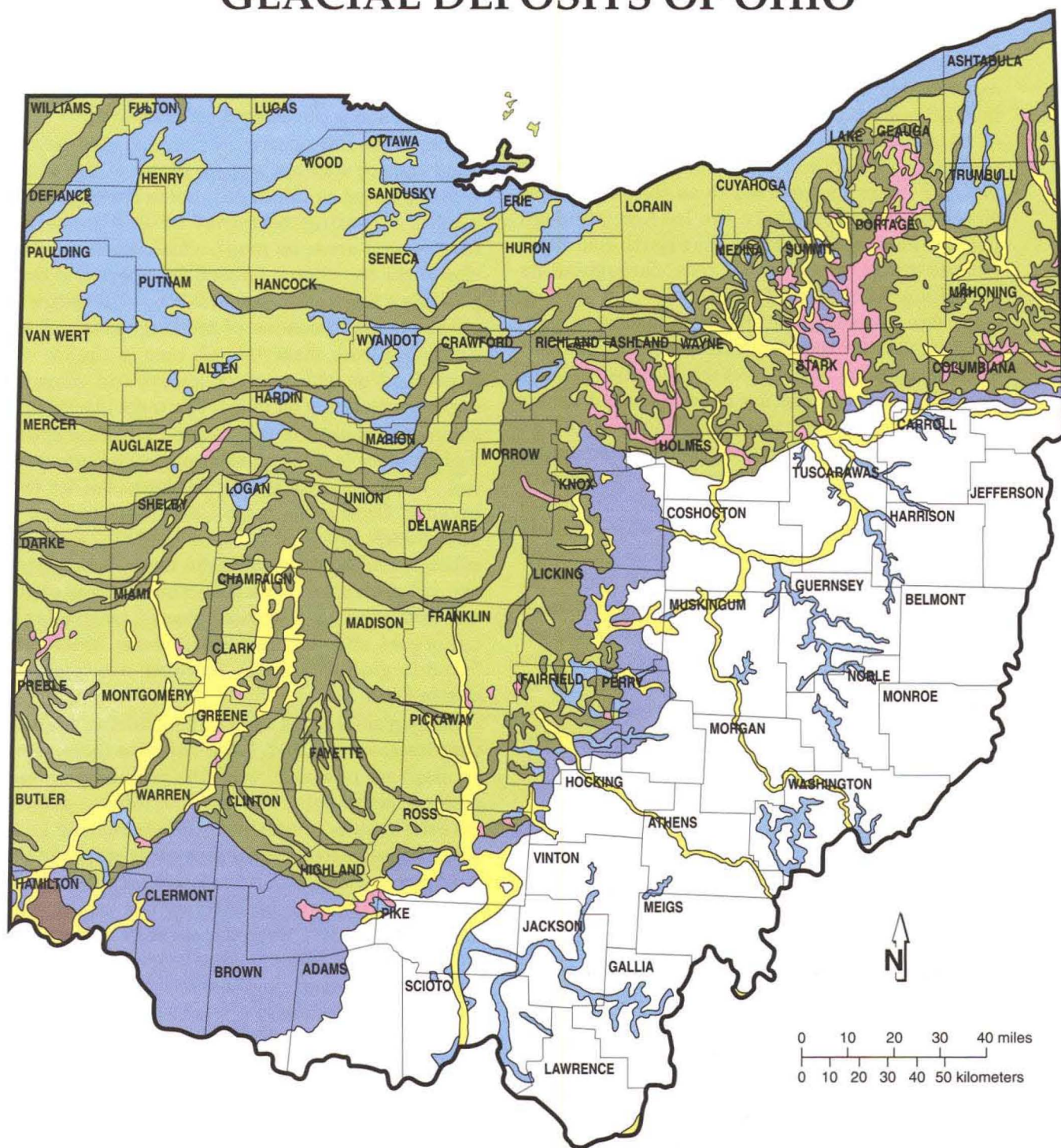
# GEOLOGIC MAP AND CROSS SECTION OF OHIO










**Figure 5.**  
**Glacial Deposits Map of Ohio**



# GLACIAL DEPOSITS OF OHIO



- |  |                  |   |   |  |   |
|--|------------------|---|---|--|---|
|  | Kames and eskers |  | WISCONSINAN<br>(14,000 to 24,000 years old) |  | ILLINOIAN<br>(130,000 to 300,000 years old) |
|  | Outwash          |  | Ground moraine                              |  | Undifferentiated morainic drift             |
|  | Lake deposits    |   | End moraine                                 |  | PRE-ILLINOIAN<br>(older than 300,000 years) |
|  |                  |   |   |  | Undifferentiated morainic drift             |



# GLACIAL DEPOSITS OF OHIO

Although difficult to imagine, Ohio has at various times in the recent geologic past (within the last 1.6 million years) had almost three-quarters of its surface area covered by vast sheets of ice perhaps as much as 1 mile thick. This period of geologic history is referred to as the Pleistocene Epoch or, more commonly, the Ice Age, although there is abundant evidence that Earth has experienced numerous other "ice ages" throughout its 4.6 billion years of existence.

Ice Age glaciers invading Ohio formed in central Canada in response to climatic conditions that allowed massive buildups of ice. Because of their great thickness these ice masses flowed under their own weight and ultimately moved south as far as northern Kentucky. Oxygen-isotope analysis of deep-sea sediments indicates that more than a dozen glaciations occurred during the Pleistocene. Portions of Ohio were covered by the last two glaciations, known as the Wisconsinan (the most recent) and the Illinoian (older), and by an undetermined number of pre-Illinoian glaciations.

Because each major advance covered the deposits left by the previous ice sheets, pre-Illinoian deposits (brown area on map) are exposed only in extreme southwestern Ohio in the vicinity of Cincinnati. Although the Illinoian ice sheet covered the largest area of Ohio, its deposits (lavender area on map) are at the surface only in a narrow band from Cincinnati northeast to the Ohio-Pennsylvania border. Most features shown on the map of the glacial deposits of Ohio are the result of the most recent or Wisconsinan-age glaciers.

The material left by the ice sheets consists of mixtures of clay, sand, gravel, and boulders in various types of deposits of different modes of origin. Rock debris carried along by the glacier was deposited in two principal fashions, either directly by the ice or by meltwater from the glacier. Some material reaching the ice front was carried away by streams of meltwater to form outwash deposits (yellow areas on map). These deposits normally consist of sand and gravel. Sand and gravel deposited by water on and under the surface of the glacier itself formed features called kames and eskers (red areas on map), which are recognized by characteristic shapes and composition. The distinctive characteristic of glacial deposits that have been moved by water is that the material was sorted by the water that carried it. The large boulder-size particles were left behind and the

smaller clay-size particles were carried far away, leaving the intermediate gravel- and sand-size material along the stream courses.

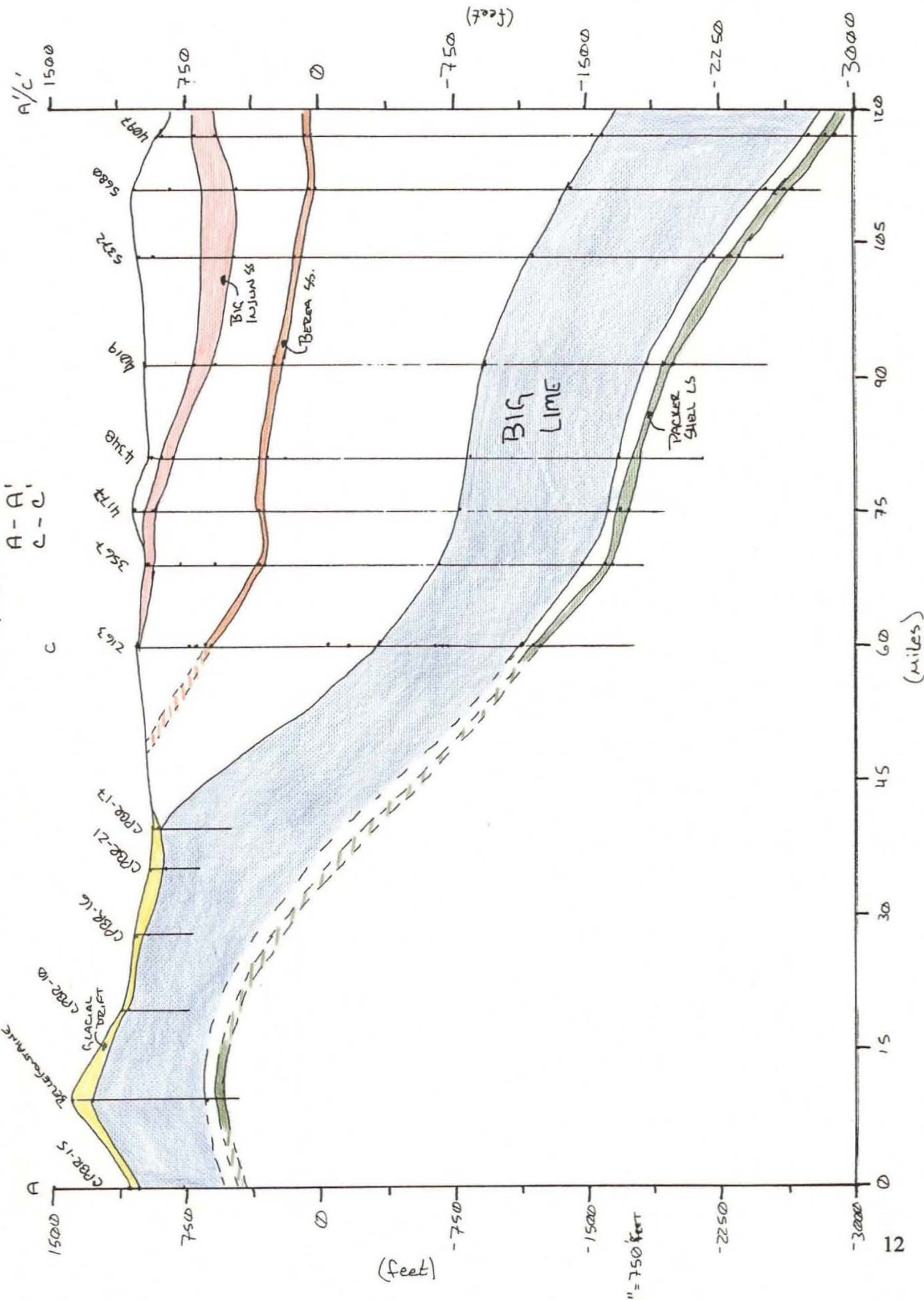
Clay- to boulder-size material deposited directly from the ice was not sorted. Some of the debris was deposited as ridges parallel to the edge of the glacier, forming terminal or end moraines (dark-green areas on map), which mark the position of the ice when it paused for a period of time, possibly a few hundred years. When the entire ice sheet receded because of melting, much of the ground-up rock material still held in the ice was deposited on the surface as ground moraine (light-green areas on map). The term glacial drift commonly is used to refer to any material deposited directly (*e.g.*, ground moraine) or indirectly (*e.g.*, outwash) by a glacier. Because the ice that invaded Ohio came from Canada, it carried in many rock types not found in Ohio. Pebbles, cobbles, and boulders of these foreign rock types are called erratics. Rock collecting in areas of glacial drift may yield granite, gneiss, trace quantities of gold, and, very rarely, diamonds. Most rocks found in glacial deposits, however, are types native to Ohio.

Many glacial lakes were formed during the time that ice covered Ohio. Lake deposits (blue areas on map) are primarily very fine grained clay- and silt-size sediments. The most extensive area of lake deposits is in northern Ohio bordering Lake Erie. These deposits represent early stages in the development of Lake Erie as it is presently known. Other lake deposits accumulated in stream valleys whose outlets were temporarily dammed by ice or outwash. Many outwash-dammed lake deposits are present in southeastern Ohio far beyond the glacial boundary.

Certain deposits left behind by the ice are of economic importance, particularly sand and gravel, clay, and peat. Sand and gravel that have been sorted by meltwater generally occur as kames or eskers or as outwash along major drainageways. Sand and gravel are vital to Ohio's construction industry. Furthermore, outwash deposits are among the state's most productive sources of ground water.

Glacial clay is used in cement and for common clay products (particularly field tile). The minor quantities of peat produced in the state are used mainly for mulch and soil conditioning.

# NORTH CROSS SECTION



1" = 15 miles

This geological cross-section diagram illustrates the subsurface structure along a profile from point B to point D. The vertical axis represents depth in feet, ranging from 15,000 at the top to -30,000 at the bottom, with a scale of 1" = 7,500 feet. The horizontal axis represents distance in miles, ranging from 0 to 120, with a scale of 1" = 15 miles. The diagram shows several distinct geological layers: BIA (Berea Limestone), BEREA SS. (Berea Sandstone), Packer Shells, and a large area of BIA LIME (Berea Limestone). A dashed line indicates a boundary or fault. The profile is labeled with various points and elevations, including B, D, and D'. The diagram is titled "BIA LIME" and "BEREA SS.".

(miles)

1" = 15 miles

**Figure 8.**  
**Stratigraphic Column of Ohio (Hull, 1991).**

GENERALIZED COLUMN OF BEDROCK UNITS IN OHIO  
Dennis N. Hull, chief compiler

Sh, sh shale  
Sa, sa sandstone  
Ls, ls limestone

Dol, dol  
cong (m)

dolomite  
conglomerate  
Percy/Visitation  
marine zone

Grp, grp  
Fm, fm  
Mbr

Group  
Formation  
Member

Depositional hiatus or interval  
removed by erosion

unconformity

Note: lower case lithologic or stratigraphic  
names indicate informal status of unit

Compiled by Dennis N. Hull from numerous published and unpublished sources and through personal communications with the staff of the Division of Geological Survey. Time boundaries from Geological Society of America.

name and the drillers' names for each rock unit. Drillers' names are used when describing the geologic units of the cross sections. The geologic units shown in the cross sections as well as the glacial deposits are described below in stratigraphic order from youngest to oldest.

The glaciations of the Pleistocene Epoch, especially the Wisconsinan, have determined the surface topography of much of the state. The glaciers left behind deposits of sand, gravel, and clay, which play a major role in the state's geology and hydrogeology. The vast majority of drinking water is supplied by wells completed in the sand and gravel deposited by the glaciers. The clay-rich tills left behind act as confining layers for the sand and gravel aquifers. These confining layers commonly separate individual aquifers and play a role in containing contamination.

The rock units that comprise the Pennsylvanian System are too numerous and nonuniform to describe in detail. For this study it is enough to know that the Pennsylvanian System of Ohio contains mainly shales, coals, sandstones, and some limestones. Rocks of this age in the study area are found predominantly in Coshocton County.

Mississippian rocks are primarily sandstones, siltstones, and shales. These rocks range in age from 320 to 360 million years BP. The upper portion of this system is missing in Ohio due to the Mississippian-Pennsylvanian unconformity. The system is capped by the Maxville Limestone in southeast Ohio. The rock units represented in the cross sections from this system are the Big Injun and the Berea sandstones (see Figure 8).

The Big Injun is the drillers' name for the Black Hand Member of the Cuyahoga Formation. The rock is primarily a conglomeratic sandstone that undergoes rapid facies change to the west and north and commonly includes siltstones and shales (Majchszak, 1984). The Big Injun is approximately 600 feet thick, with the top 350 feet being the Black Hand Member. This unit is often

cross bedded and has an original dip of 5 to 15 degrees north to northeast. The depositional environment is thought to be a shoreline deposit or a river emptying into the Waverly Sea, with source material to the south at no great distance (Hyde, 1953).

The Berea Sandstone is the other unit of the Mississippian System shown in the cross section. The name Berea is used by both geologists and drillers. It is a massive, brown to light bluish gray, fine-grained sandstone with a subsurface thickness ranging from 5 to 50 feet (Hyde, 1954), although it has been seen in outcrop as thick as 200 feet (Lamborn, 1953). The Berea is a reservoir rock of many small oil and gas pools in eastern Ohio. It is usually underlain by black-brown shale (Lamborn, 1953).

The 850-1200 foot thick Devonian-Silurian carbonate unit known by the drillers' name Big Lime is composed of many carbonate beds and is the primary unit of interest in this study. The Big Lime consists of a series of limestones and dolomites, and extends from the Middle Devonian to the Middle Silurian. The unit is overlain by several hundred feet of Devonian shales and is underlain by the Silurian Osgood Shale (Lamborn, 1953).

The Devonian members of the Big Lime are the Delaware and Columbus Limestones. These units together have an average thickness of approximately 175 feet and consist of gray, microcrystalline limestone with traces of chert (Lamborn, 1953).

The Silurian members of the Big Lime in the study area are the Bass Islands Group, also known as the Salina Undifferentiated, Tymochtee, Greenfield, and Lockport Formation. All these units are dolomites of varying quality and thickness. The average thickness of the Silurian units of the Big Lime is approximately 900 feet. About 100 to 300 feet above the base of the Big Lime is a zone of very porous dolomite. It is within this unit that brine is predominantly found. This unit is

known to drillers as the "Second Water". Its porous nature and wide distribution are thought to correspond to an erosional horizon. This unit is overlain by a thin unit that has been known to yield oil and gas over limited areas and is known as the Newburg "sand" (Lamborn, 1953). The depositional environment of the Devonian-Silurian carbonates was a shallow warm water, epicontinental sea that covered Ohio for most of the Paleozoic Era.

Packer Shell is the drillers' name for the Lower Silurian rock unit known to geologists as the Dayton Formation. The Dayton Formation is a thin unit of bluish gray dolomitic limestone that is fine to coarsely crystalline and is commonly referred to as the Little Lime. The unit has a thickness ranging from 5 to 40 feet, averaging about 22 feet. The Packer Shell is overlain by approximately 100 feet of soft argillaceous shale, the Osgood Shale, which separates it from the Big Lime (Lamborn, 1953).

## **MATERIALS AND METHODS**

This thesis utilizes several different types of geologic data to determine the geology, stratigraphy, and depth to brine within the study area. The most important of which is the "header cards" and geophysical logs from oil and gas wells archived in ODNR's Geologic Records Section. These cards show the depth to top of formations down hole as well as the thicknesses of the geologic units. They also record the location of the well in State Plane X-Y coordinates and by county and civil township (section and lot). Various other data are given on these cards such as surface elevation, total depth of hole, drilling dates, casing lengths, landowner, driller, and other noteworthy information (Figure 3). These cards were the only source found recording the depth to brine in all the different record types investigated.



ODNR Division of Geological Survey core logs were also used to determine depth to the top of the various geologic units described above in the Geologic Setting section of this thesis and shown in the geologic cross sections ( Figures 6 and 7). Figure 9 is an example ODNR core log. In addition to the core logs and well "header cards", depths to geologic units were determined using selected data of previous work completed by ODNR Division of Geological Survey's Bedrock Mapping Group. These records included studies in Logan, Union, and western Delaware counties. These records do not provide depth to brine information but do provide excellent depth to geologic unit information. Figure 10 shows an example log from the Bedrock Mapping Group's previous studies.

A LOTUS 1-2-3 spreadsheet was used to compile Licking and Coshocton county data on depth to top of the Big Lime, depth to brine horizon, bottom of the Big Lime, surface elevation, and X-Y State Plane coordinates. These data were then saved as a SURFER Worksheet and gridded for use by the SURFER for Windows contouring program. Using the gridded data files, structure-contour maps and 3-D surface plots were created, as shown in the following figures. Figure 11 is the structure-contour map on the top of the Big Lime in Licking County and Figure 12 is a 3-D surface plot of the top of the Big Lime in Licking County. Figure 13 is a structure-contour map on the brine horizon in Licking County and Figure 14 is a 3-D surface plot on the brine horizon in Licking County. Figure 15 is a structure-contour map on the top of the Big Lime in Coshocton County and Figure 16 is a 3-D surface plot on the top of the Big Lime in Coshocton County. Figure 17 is a structure-contour map on the brine horizon in Coshocton County and Figure 18 is a 3-D surface plot of the brine horizon in Coshocton County. A discussion based on these figures follows.

Figure 9.

Example ODNR Core Log

Water Well CPBR-17

Ostrander Quadrangle

Delaware County

X= 1,779,050

Y= 232,100

Scioto Township

Elevation (G) 940 feet

VMSL 5868

0 - 30	No samples
30 - 40	Dolomite, light- and medium-gray- to brownish-gray, microcrystalline. Shale, dark-gray, trace
40 - 50	Dolomite, light-brown, microcrystalline (dolomicrite and dolosiltite), mottled light-green and dark-brown in part. Shale, dark-gray, trace
50 - 60	Dolomite, very light- and light-brown and gray, microcrystalline, argillaceous in part. Shale, light- and medium-green, dolomitic in part, 5%
60 - 70	Dolomite as above, laminated with shale, medium- and dark-gray
70 - 80	Dolomite as above, pelletal and oolitic in part, brecciated in part, contains black platy fragments
80 - 90	Dolomite, light-yellowish-brown, microcrystalline (dolomicrite), fair pinpoint to vuggy porosity
90 - 100	Dolomite, light-yellowish-brown and brown, microcrystalline (dolo- micrite and dolosiltite), porosity as above
100 - 110	Dolomite, medium-brownish-gray, microcrystalline (dolosiltite); ex- cellent pinpoint porosity in part; shale partings, black, heavy trace. Gypsum nodules, trace
110 - 120	Dolomite, light-brown- to grayish-brown, microcrystalline (dolomicrite). Shale, medium-green, gypsum nodules, heavy trace
120 - 130	Dolomite, light-brown to yellowish-brown, light-gray, microcrystalline (dolomicrite and dolosiltite), gypsiferous poor to fair pinpoint porosity. Gypsum, heavy trace

Figure 10.

Example Well Log from ODNR's Bedrock Mapping Group.

ODNR File No. 2641  
DIVISION OF GEOLOGICAL SURVEY

CORE RECORD

County: Delaware Township: Scioto Section or Lot:  
Measured: Ft. from Line, and Ft. from Line  
Location Remark:  
Property owner: Fawcet farm  
Core Hole Designation (project): SSC-12  
Purpose of Core: Bedrock Mapping  
Driller: Roy Dawson/Bill Dunfee  
Drilling Co.: ODNR, Division of Geological Survey  
Drilled For: ODNR, Division of Geological Survey  
Surface Elev: 943' Datum for Elev: Sea Level  
Date Started: 3-30-87  
Date Completed: 4-4-87  
Logged By: Ronald G. Rea  
Core Diameter: 1 7/8"  
Total Depth: 310'  
Core Disposition: Stored in the core repository of the ONDR, Division of Geological Survey  
Remarks: This site is located alongside a farm pond 3,500' east of the Delaware-Union County line and 11,000' north of U.S Route 36

Quadrangle: Ostrander  
State Coordinates X: 1,794,375 Zone  
Y: 230,700

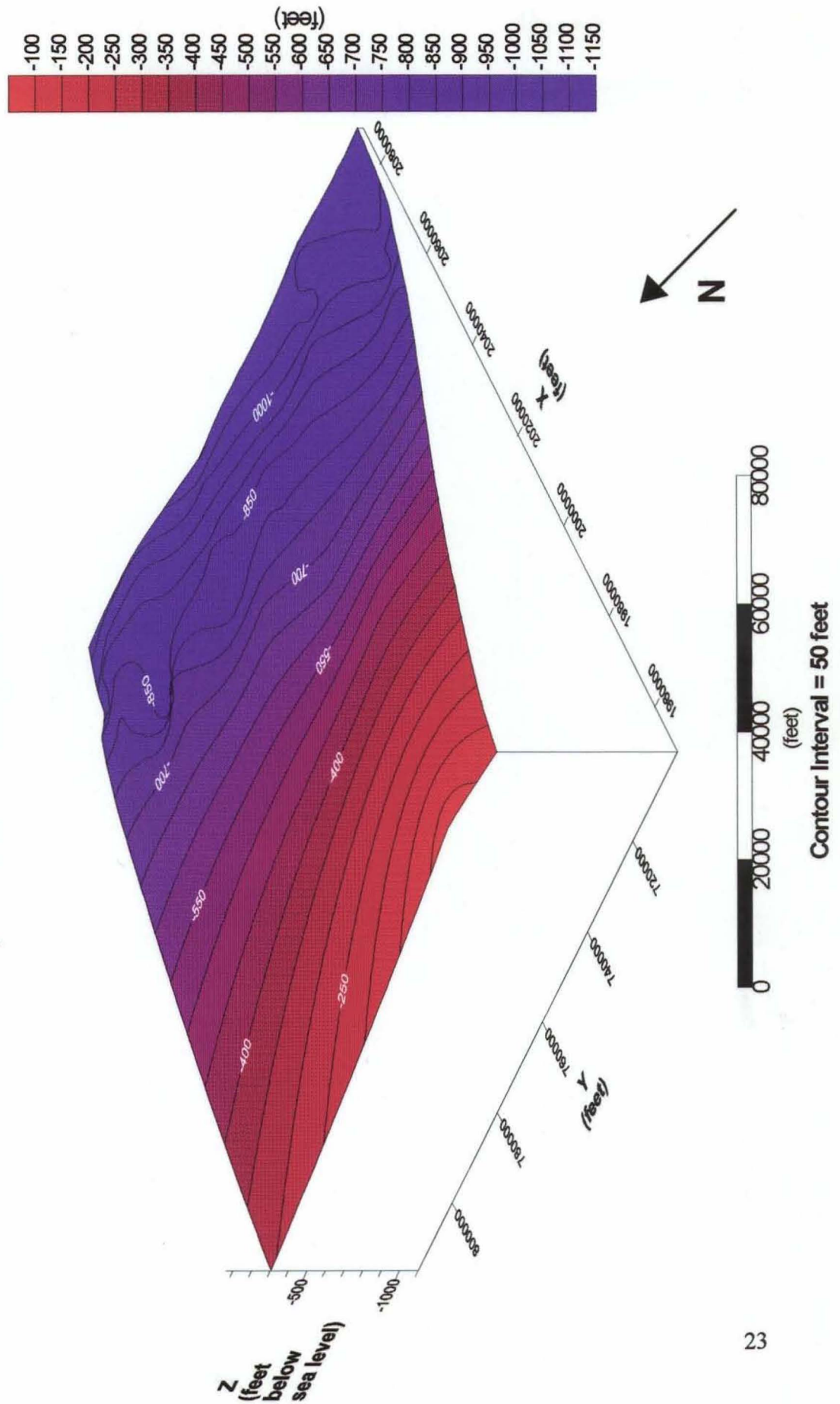
THE DIVISION OF GEOLOGICAL SURVEY MAKES  
NO AFFIRMATION CONCERNING THE COMPLETENESS  
AND ACCURACY OF THIS INFORMATION.

TOP Ft.	BOTTOM Ft.	INTERVAL Ft.	DESCRIPTION
0.00	38.00	38.00	Soil, unconsolidated sediments.
38.00	62.70	24.70	Dolomite, very pale orange (10YR 8/2), micritic, very even textured and homogeneous; abundant fractures; much solutioning has occurred along fracture surfaces; core is badly broken; core loss 38.00' - 58.00' 61.60' - 62.40'; small pieces recovered during numerous runs indicates the missing core to be of all the same lithology.
62.70	71.70	9.00	Dolomite, yellowish-gray (5Y 7/2) to medium-gray (N5), micritic to very fine grained; mottled texture; scattered zones of vuggy porosity; some vugs calcitic; scattered shale streaks and partings near bottom of unit; grades into unit below.
71.70	76.25	4.55	Dolomite, medium-gray (N5) to light-gray (N7), very fine grained; mottled texture, moderate zones of thin laminations; porosity is intergranular and vuggy; core badly weathered and broken; core loss 73.00' - 76.25'.
76.25	87.25	11.00	Dolomite, medium-light-gray (N6), very fine crystalline to very fine grained, hard; calcite streaks and calcitic laminae; scattered throughout unit; shale streaks sparse in upper portions becoming abundant below; 45° fractures 82.70' -

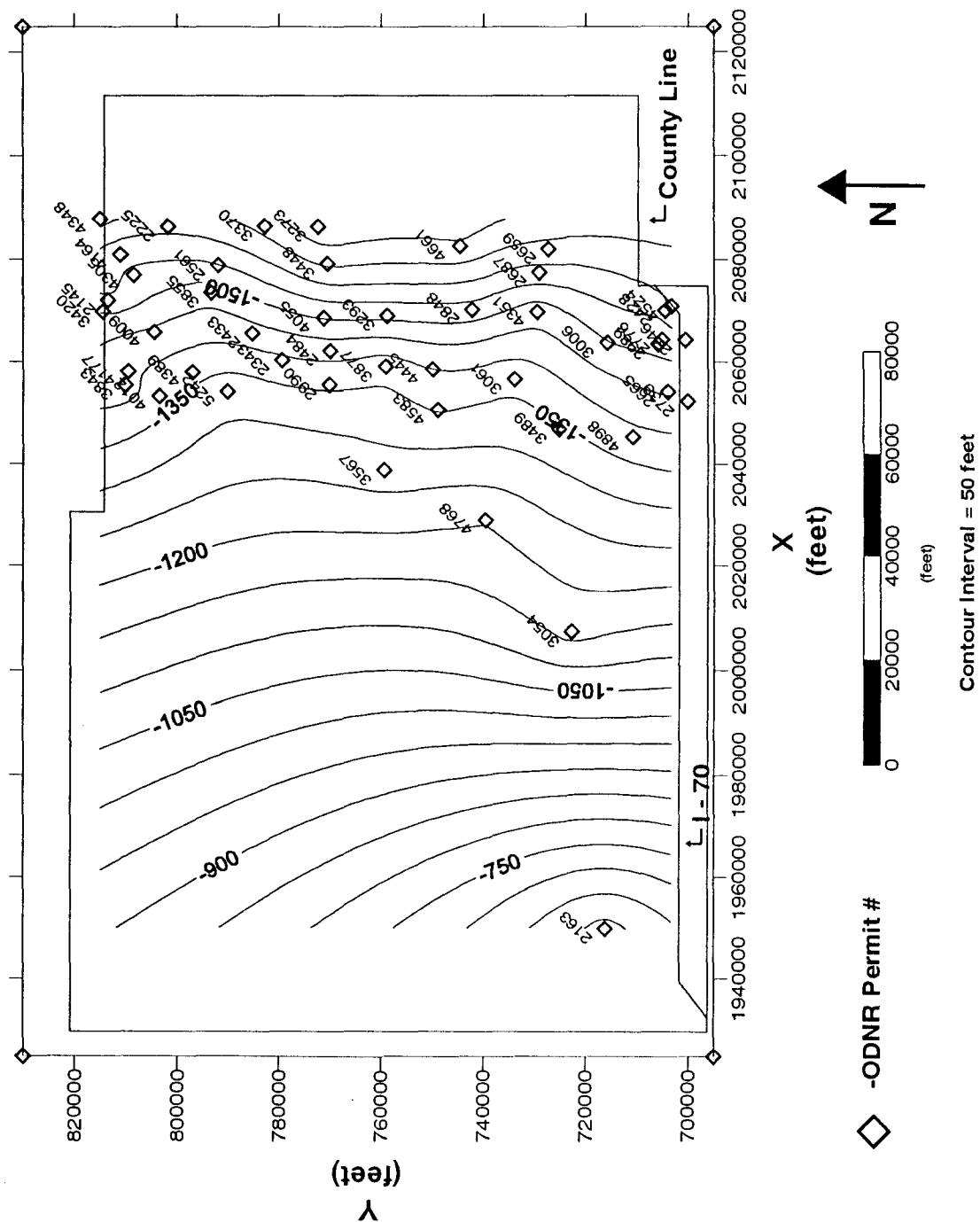
**Figure 11.**



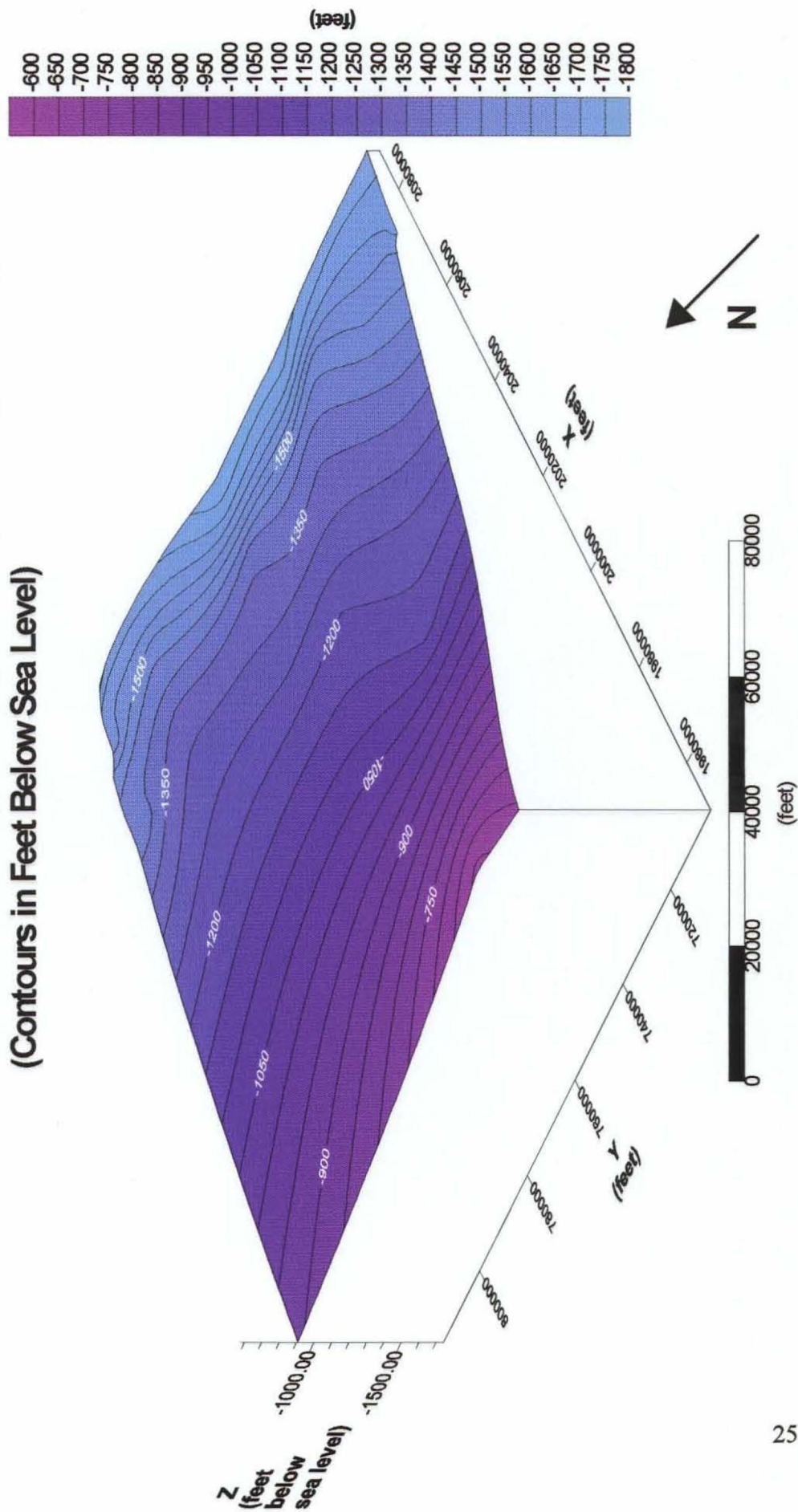
**Figure 12.**  
**3-D Surface Plot of the Top of Big Lime, Licking County, Ohio**  
**(Contours in Feet Below Sea Level)**



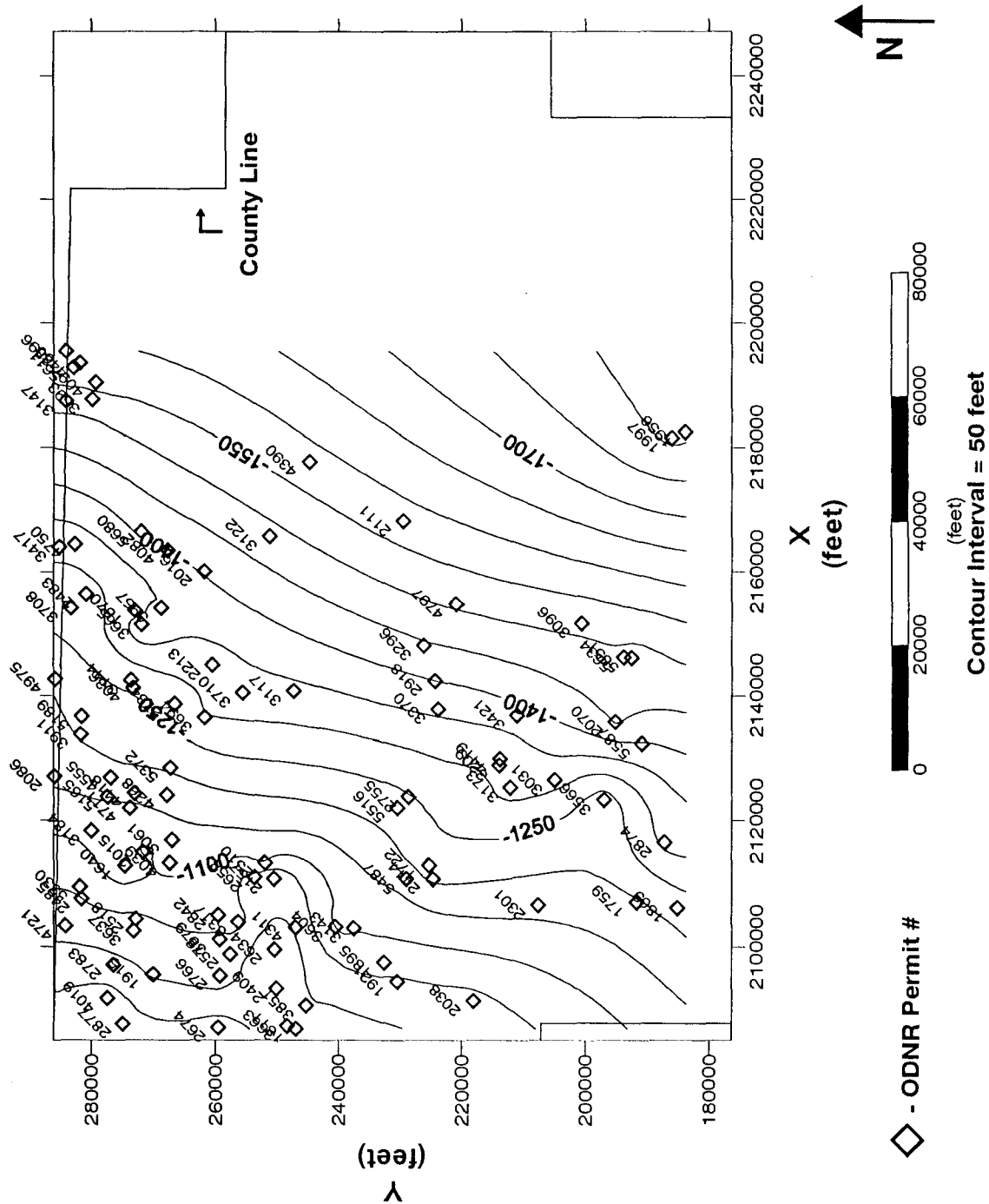
**Figure 13.**  
**Elevation of First Brine Horizon Reported by Drillers, Licking County, Ohio**  
**(Contours in Feet Below Sea Level)**



**Figure 14.**  
**3-D Surface Plot of First Brine Horizon Reported by Drillers, Licking County, Ohio**  
**(Contours in Feet Below Sea Level)**

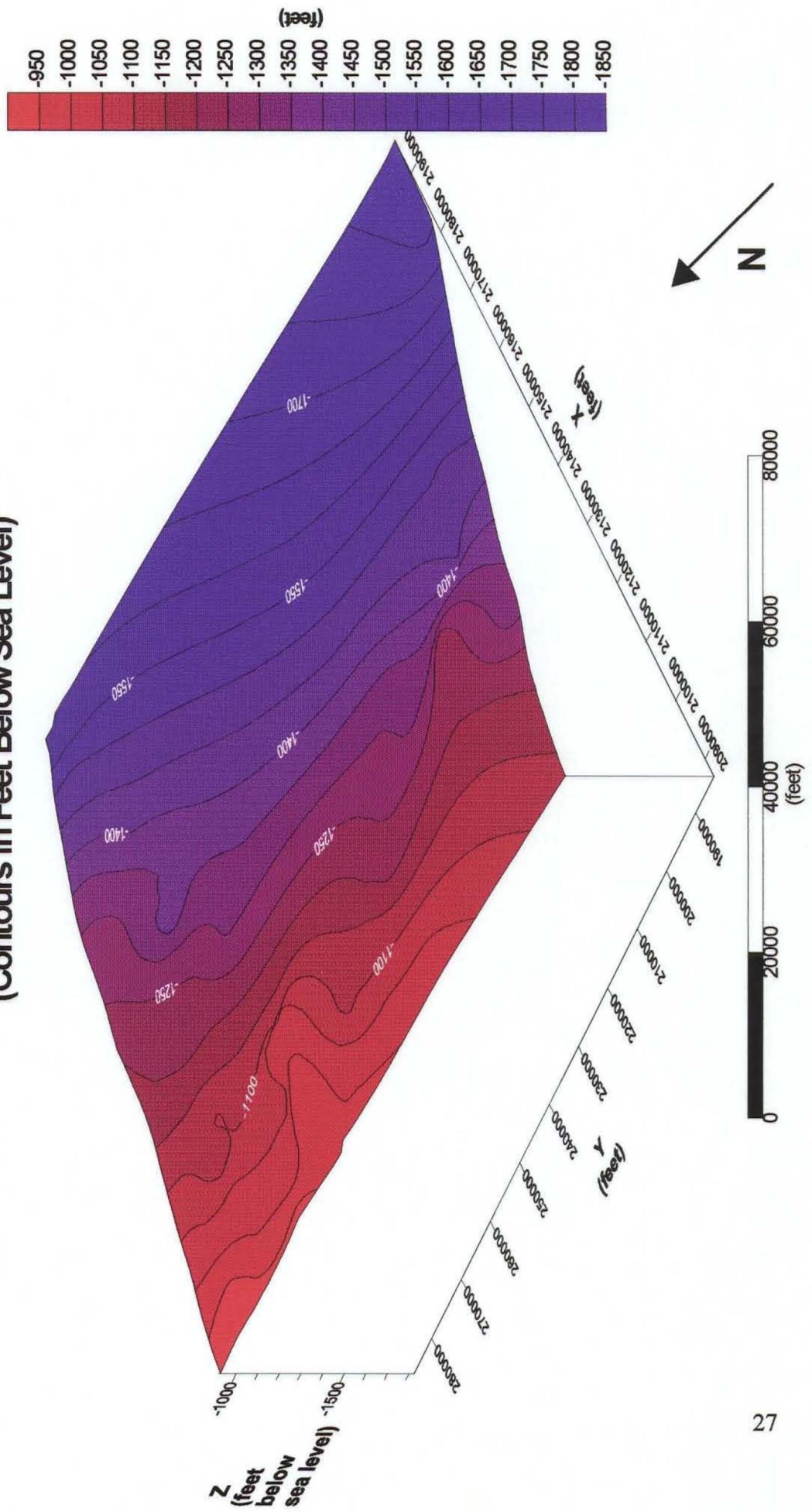


**Figure 15.**  
**Structure Contour Map of the Top of Big Lime, Coshocton County, Ohio**  
**(Contours in Feet Below Sea Level)**



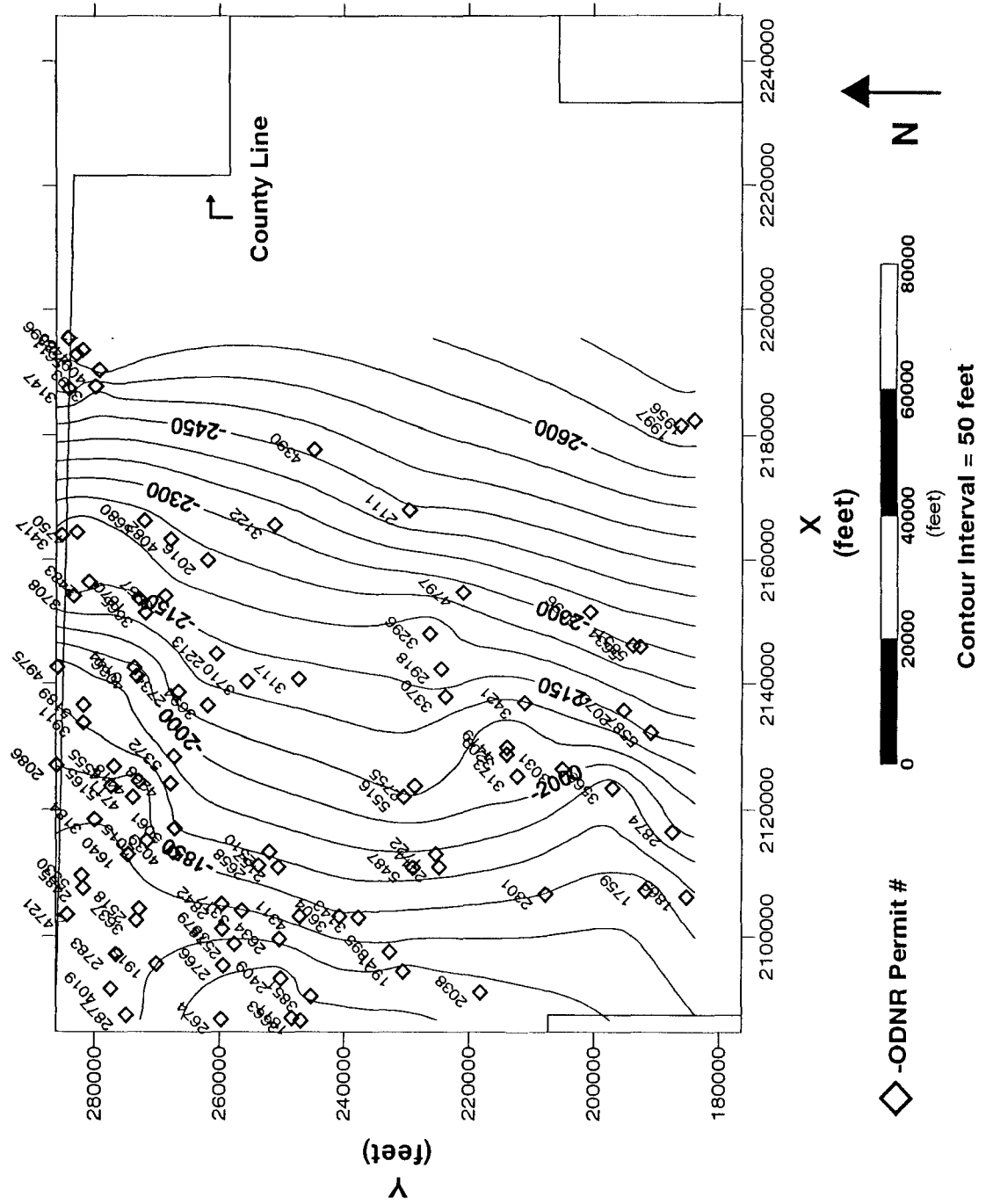


**Figure 16.**  
**3-D Surface Plot of the Top of Big Lime, Coshocton Countrny, Ohio**  
**(Contours in Feet Below Sea Level)**

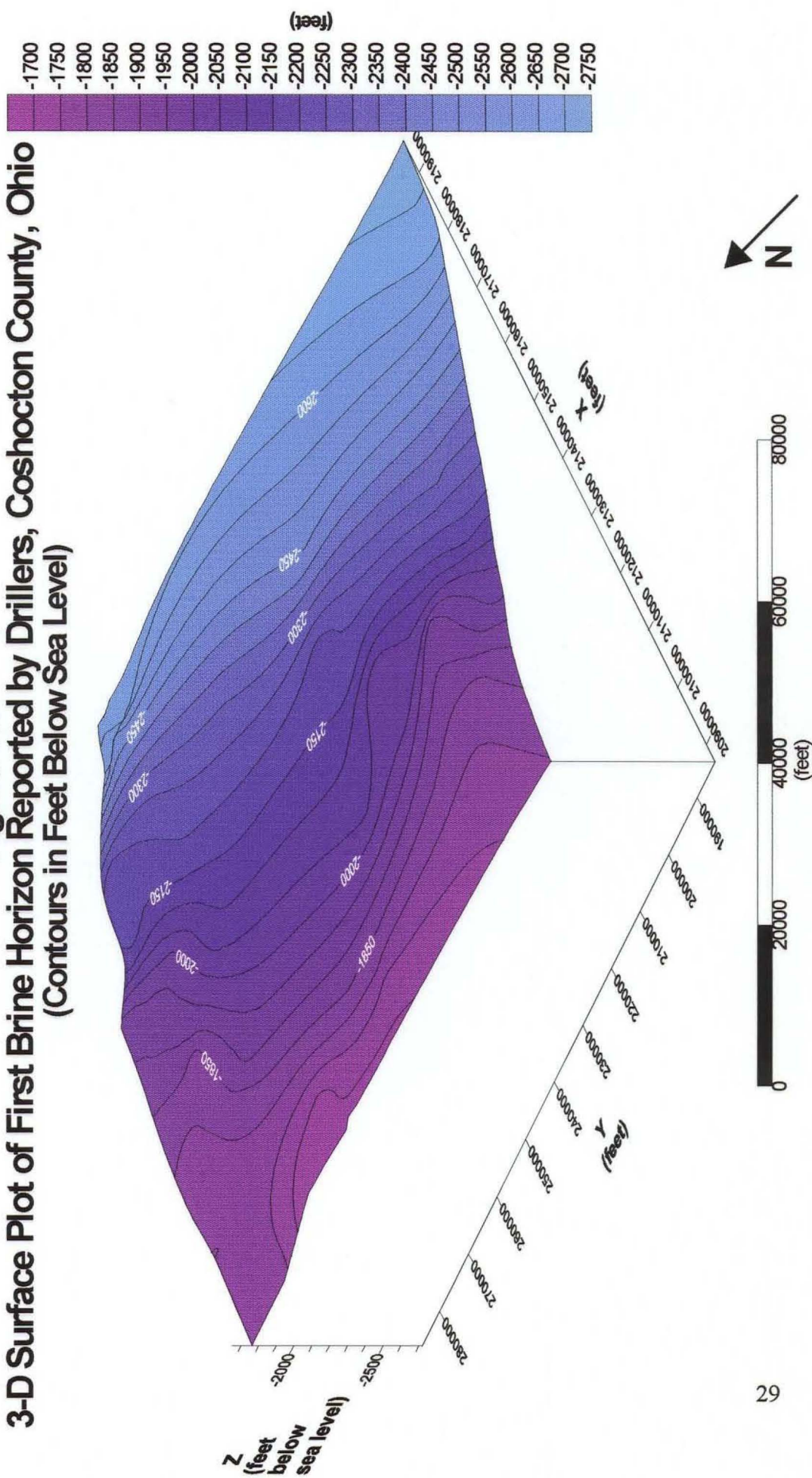


Contour Interval = 50 feet

**Figure 17.**  
**Elevation of First Brine Horizon Reported by Drillers, Licking County, Ohio**  
**(Contours in Feet Below Sea Level)**



**Figure 18.**  
**3-D Surface Plot of First Brine Horizon Reported by Drillers, Coshocton County, Ohio**  
**(Contours in Feet Below Sea Level)**



Contour Interval = 50 feet

## RESULTS AND CONCLUSIONS

Interpretation of Figures 11-14 for Licking County and Figures 15-18 for Coshocton County, shows that the top of the Big Lime continues its dip to the east, as is expected due to the Cincinnati Arch. The Brine Horizon also follows this eastern dipping trend, which can be seen in the 3-D surface plots of both the top of the Big Lime and the brine horizon for Licking and Coshocton counties. Note that, the eastern edges of the beds are at a higher elevation than at the center or western edges (Figures 11-18).

Figure 19 shows a plot of the top of Big Lime and the brine horizon in depth below sea level. The x-axis of the plot (see Figure 19) is in feet and corresponds to the wells' State Plane Coordinates. Figure 19 runs from C-C', which is a subdivision of the geologic cross section A-A'. Figure 19 shows that the brine horizon dips to the east at a slope of approximately 45 feet per mile, whereas the top of Big Lime dips to the east at approximately 33 feet per mile. Therefore, the brine horizon appears to relate to the top of Big Lime in a manner that most closely matches Scenario B of Figure 2: the brine horizon dips at a steeper angle than the parent bed.

A plot of the top of Big Lime and the brine horizon along D-D', a subdivision of the geologic cross section B-B', can be seen in Figure 20. The X and Y-axes of the plot represent the same measurements as in Figure 19. Figure 20 shows that the brine horizon dips to the east with a slope of approximately 48 feet per mile compared to the top of Big Lime, which dips to the east with a slope of approximately 40 feet per mile. These results also appear to support the interpretation (Scenario B of Figure 2) that the brine horizon dips at a steeper angle than the parent bed. The consistent manner in which its dip increases leads to the conclusion that the brine in the Big Lime does indeed run along a sub-bed of the Big Lime, which may represent an erosional surface, as

FIGURE 19. TOP OF BIG LIME AND  
BRINE HORIZON C - C'

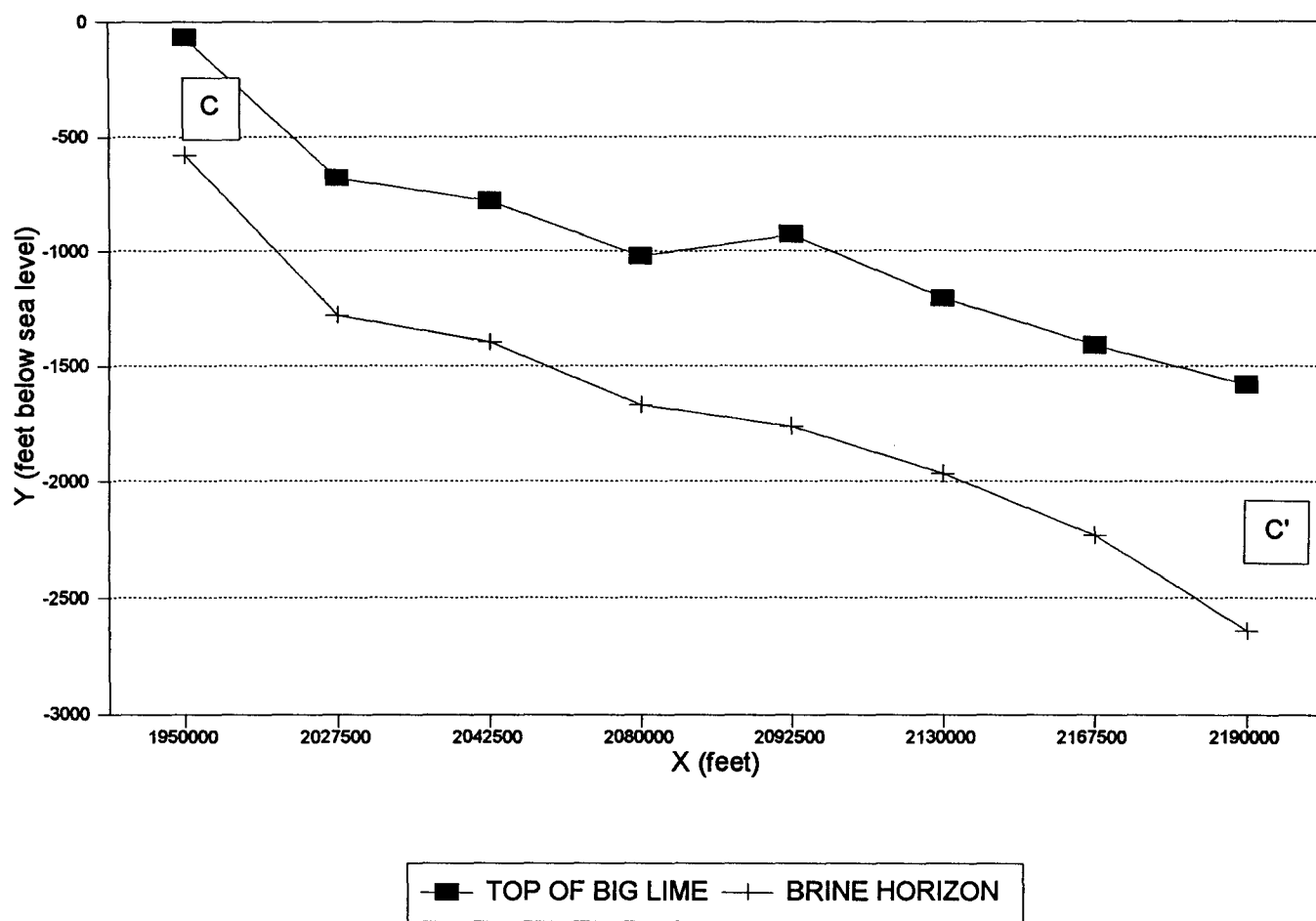
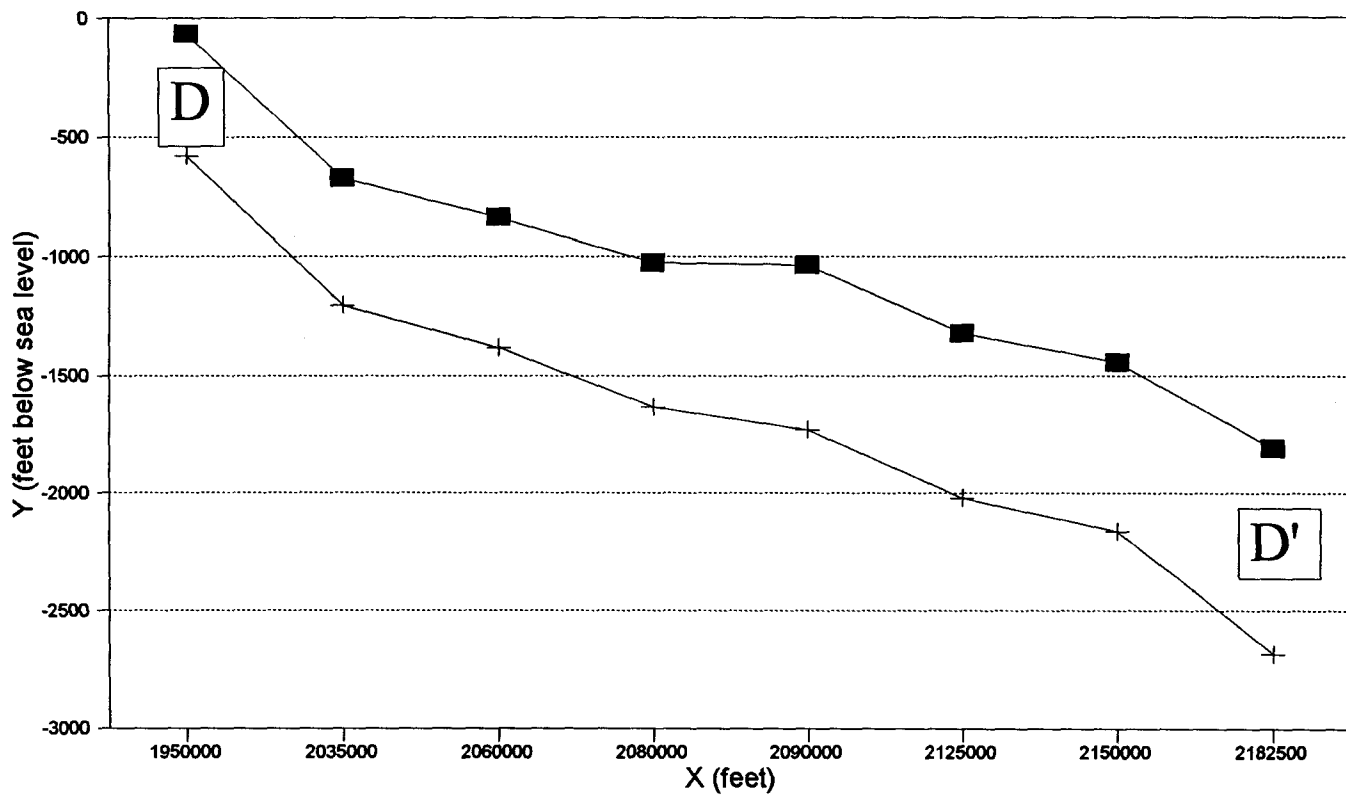


FIGURE 20. TOP OF BIG LIME AND  
BRINE HORIZON D - D'



■ TOP OF BIG LIME    + BRINE HORIZON



suggested by Stout *et al* (1932).

Although the method described above is the best suited given the available data, the possibility for error does exist. One potential source of error is in the data. Methods for determining that the formation water is saline is not standardized. This determination can take the form of an educated guess by the driller or geologist on site, the use of a chemical test to determine the salinity of the water, or simply by the driller tasting the formation water. Another source of potential error is the distribution of the data. For example, the data in Licking County are clustered in the east, which can create false contours due to large distances between data points and edge effects created by the contouring program. Also, a potential problem is that recording the depth to brine is not required during the drilling or logging of petroleum wells. Still another factor that could cause error is that recording the depth to brine is not done when cores are drilled, this would add greatly to the amount of available data by yielding data outside the confines of the oil and gas fields.

This conclusion will be useful in determining the approximate depth to brine in future drilling operations and in defining the flow path of any brines introduced into the Big Lime by injection. Determination of depth to brine will also assist in decision making concerning injection well use for the disposal of petroleum-industry brines.

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